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IN A MODERN PLANE

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IN A MODERN PLANE

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ABSTRACT. The era of jet propulsion brought forth not only great speeds and flight altitudes, but also many unusual and difficult-to-explain mistakes which were made by crew members, particularly during landing. Their true causes were uncovered with the aid of engineering psychology.

The brochure talks about the peculiarities of the pilot's work in a popular form, using many concrete examples. It discusses engineering psychology which helps pilots in their work. It tells the reader about the newest devices available in the scientific organization of work, and gives information on the biomechanics of the human organism. One of the chapters is devoted to a description of the cockpit as it will look in the near future.

The brochure was written for pilots, service engineers and technicians, students attending All-Union Voluntary Society for Assistance to the Army, Air Force and Navy of the USSR (DOSAAF) schools and of course, for wide circles of our young people that are interested in the achievements and future prospects of aviation.

INTRODUCTION

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"...Lieutenant K. was guiding his fighter plane toward the testing range. The sky was bright and cloudless, and the lieutenant had confidence in himself. The testing range gave a command to fire. The pilot barely released the controls and pushed the button used to reload the weapons. Suddenly the plane shuddered as if something broke off from it. The pilot shot a glance at the

*Numbers in the margin indicate pagination in the original foreign text.

Details of illustrations in this document may be better studied on microfiche

instrument panel and understood what had happened. Instead of the button used to reload the weapons, he pressed the button used to drop suspended gasoline tanks...".

"...Due to an incorrect use of the barometric altimeter readings, two aircraft came within a dangerously close distance of each other...".

"...Pilot N. made a serious error in the calculation of landing...".

Similar reports became particularly common in the first postwar years when the era of jet aviation began, and the range of speeds and altitudes of flight increased sharply. Flights' objectives have widened and their conditions have become more complex. In addition, the demands on the accuracy with which a plane is to be guided along a given trajectory have increased enormously. At the same time it was found that crewmen started to make unusual errors which were hard to explain. The navigators took incorrect readings on their instruments, pilots pulled the wrong levers, and made mistakes in pressing buttons.

Similar alarming signals came from other branches of service, and even from the industry.

The problem is that in the past two decades due to the progress in aerodynamics, theory of jet motion, automation, and radio electronics there has occurred a rapid rise of the speed and power characteristics of the "mechanized army". This led to a situation where machines began to "impose" on their operators "nonhuman" requirements. The pilot could not follow the readings of dozens of instruments and indicators, and manipulate a multitude of switches.

Voices began to be heard: "once the 'human element' became an obstacle to progress, it should be eliminated from the control of machines." "Humans think slowly and have a poor memory, they cannot think clearly, often make errors, and tire fast. For those reasons we have to replace man with a fully automated machine!" In those years a technocratic slogan "Down with man!" originated.

The technocratic boom did not spare aviation. A number of pressing problems, related to progress in aircraft technology, have been put in second place. Newspapers became full of popular headlines: "The future belongs to rockets," "Rockets are capable of everything," and incompletely tested aircraft were scrapped, melted, or cut in pieces... /4

Then suddenly the slogan "Down with man" began to disappear from the pages of Western press. It turned out that rockets are far from being capable of everything, and that man is in general not that inferior. It turned out, for example, that he can take into account the probability of events and is able to predict their development, that he maintains his memory in a constant "battle" readiness, etc. The conclusion that man is useless turned out to be clearly premature, and the slogan "exclude man from control systems" was replaced by the slogan "symbiosis of man and a machine." This realistic solution did not at all come at once but as a result of a long and painstaking cooperation among scientists and specialists in various areas of knowledge: mathematics, automatic control theory, psychology, and physiology. A new applied discipline came into existence. Its name was engineering psychology, and it was in essence a branch of technical cybernetics.

Engineering psychology (or, as it is still called abroad, technical psychology, human factors technology, applied experimental psychology, psychophysics, psychotechnology, etc) is one of those disciplines that are born at a junction of various sciences: it closely combines the methods and problems of areas that are distant from each other in any classification of sciences.

Engineering psychology reveals the existence of general principles of engineering design of complex automated systems of the type man-machine, their optimal designs, and technical characteristics taking into account the capabilities of the operator. It also explores the psychophysiological potentialities of the human organism; it develops the scientific methods of the selection and training of operators.

Engineering psychology came into existence on the crest of a scientific and technological revolution. The Directives of the 24th Congress of the Communist Party of the Soviet Union contained this passage regarding the ninth 5-year plan: "Accelerate the rate of the scientific and technological progress by energetically developing research in the most promising areas of science..., replace manual labor with machines on a wide scale." Studies in the area of engineering psychology will undoubtedly bring about an even greater increase in the efficiency of complex industrial processes in systems "man-machine" in all areas of the national economy; they will enable one to solve a number of complicated problems caused by the intensification of ground and air transport.

MAN IN A CONTROL LOOP

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The man-machine system is the basic object of study in both the general area of the scientific organization of work and, in particular, in engineering psychology. The man-machine system is veiwed as one of the forms of control systems. In a system of this type man and a machine form a single control loop. In its study of the control processes taking place in the man-machine systems, their composition and functions, engineering psychology considers the human operator as one of the links in such systems.

It is unquestionably true that the work of a machine and the activity of man are radically different. Man, when included in a control system, performs a consciously set task. A machine is merely a "blind follower" of the human will. It is also unquestionable that the processes occurring in technological

devices (no matter how perfect they are) differ qualitatively from the psychological processes peculiar to man. Nevertheless, modern science finds many analogies between man and a machine. Moreover, life requires a creation of such concepts that would permit one to view man and machine from a single viewpoint.

The qualitative differences between man and a machine do not exclude the possibility of viewing them in a strictly defined sense as members of a single control system. This is precisely the point of view of engineering psychology. The latter does not require at all that the activity of man be identified with the operation of a machine or that machines be ascribed characteristics that are peculiar only to man.

In order to clarify the point of view of engineering psychology, let us turn to a concrete man-machine system. Suppose that a man controls a certain object. Whether it is an air dispatcher, a pilot flying a plane with no ground visibility, or an operator of a guidance post, in all cases the control process has certain common features. All changes in the controlled object (in this case, a plane) are monitored by means of some sensors; the signals from the sensors are converted and displayed on instruments that are watched by a human being. The man perceives the instrument readings, deciphers them, makes a decision, performs a certain action, that can be either very simple (for example, pressing a button) or more complicated. The signal produced as a result of the human activity is converted and fed to the controlled object, effecting a change in its state. The new state of the object causes changes in the instrument readings which inform the operator of the results of his action. This, in turn, may produce new actions. /6

These are the general features of a closed control system in which a man connected through direct and feedback couplings with the controlled

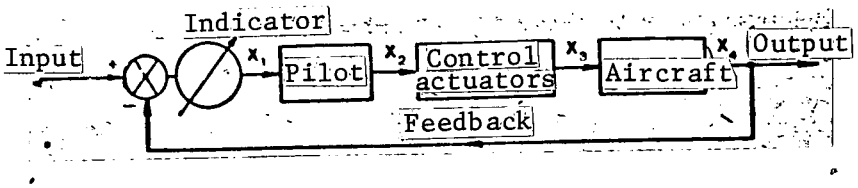

Figure 1. The pilot in the aircraft control loop.

object appears in the role of the most important, most crucial of the system, i.e., the regulator[1]. Of course, it is possible for a man not to receive any information about the results of his actions. Then he is considered as a link in an open system.

Figure 1 shows an elementary structural single-loop diagram of a closed man-machine system. The control process proceeds here in the form of a series of transitions of actions from one member of the loop to another (X_1, X_2, X_3, X_4). In addition, the state of any member affects the other members, and is in turn affected by them.

In reality it often happens that a single operator controls a number of objects or several people control a single object. The coupling between the human regulator and the regulated object may also be more complicated and may include a greater number of members (indicators, actuators, etc.). Along with the main loop, control systems may also include additional loops. In those cases a block diagram of the man-machine system will be more complicated.

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[1] In control theory the direct coupling is defined as that part of a control loop in which a signal travels from the regulator to the object, and the feedback coupling is defined as the remaining part of the control loop, i.e., in the direction from the object to the regulator. Thus, the feedback signals carry information about the way in which the object reacts to the command signals from the regulator.

The basic parameters of a control system, namely the control cycle time (speed), carrying capacity, accuracy, and reliability, are to a considerable extent determined by the capabilities and peculiarities of its integral link: man. Without analyzing his characteristics it is impossible to either understand the work of a system as a whole or to correctly design it.

Experience shows that a poor knowledge of psychophysiological characteristics of humans has the effect in the area of control system design that a system is not able to function or its functioning is partially impaired which may sometimes end in a breakdown or in a premature fatigue of the operator (and this lowers the reliability of the entire system). Thus, according to the data of American researchers, a significant fraction of breakdowns in aviation is due to the so-called human factors, often the pilot's errors. They occur because the pilot did not perceive the instrument readings accurately, took one instrument for another, confused controls, did not react quickly enough, etc. /7

In the United States the appearance of supersonic aircraft was first accompanied by puzzling accidents. Their causes were eliminated by specialists in the area of engineering psychology. They found that in a flight at Mach 3 the pilot suffers from a peculiar illusion: he continues to see objects that were left behind at a distance up to 100 m, as if they were alongside the plane. This is due to the fact that the characteristics of visual perception and the motion of a supersonic plane are incommensurable. It is as if the rate of perception lagged behind the speed of a plane.

It should be noted that already toward the end of World War II the speeds of approach of two planes in a collision course were about 1,000 km/h. It was thought that on the average human beings can react to external signals (i.e., to perform any useful activity) no more frequently than once every 0.5 sec. Theoretically it follows that if a pilot of a plane moving in the opposite direction to an enemy plane does not turn his plane 150 m from the point of

collision (during 0.5 sec the planes approach each other by 150 m), then he will not be able to move the rudder in time. However, there were cases when Soviet pilots turned their aircraft at distances shorter than theoretically possible, and fired at the enemy point-blank. This means that under critical conditions it is possible psychologically to regulate the physiological capabilities of the organism!

The functions of human beings in the man-machine systems are very diverse. He may play the role of a receptor of information coming in this or other form from the controlled object. He may be simply an amplifier and converter that transmits information from one link of the system to another. He may analyze information and make decisions, i.e., produce control or command information. Human beings may also program the operation of an entire system or its parts. He may monitor and control the operation of a system. Finally, the operator /8
may carry out commands, i.e., perform actions that are aimed directly at a change in the controlled object. Usually man combines a number of functions, performing them consecutively or simultaneously.

In various stages of the control process some functions may be dominant, and others auxiliary. The range of human participation in control systems is extremely wide.

MAN IN FLIGHT

In the opinion of specialists, at the present time there are two areas that are of greatest interest from the point of view of the investigation of the maximum capacities of man included in a control loop. They include: flying jet planes at low altitudes and in-flight refueling.

Low Altitudes. Progress in the area of surface-to-air missiles poses a serious threat to aircraft attempting to fire at targets from high altitudes.

For this reason a great deal of attention is given abroad to the development of ways in which aircraft can approach a target at the altitude of 150-50 m and even below at speeds ranging from Mach 1 to Mach 1.5[2]. Since under those conditions it is difficult to separate a signal from an approaching plane against the background of noise from local objects, a plane that has penetrated an enemy territory will not always be detected by a radar station located on the ground or on fighter-interceptor aircraft.

However, as the altitude decreases and the speed of flight increases, the danger of collision with ground obstacles becomes greater. As a result, for each concrete type of aircraft it becomes necessary to determine the most convenient speed and altitude ranges taking into account the characteristic features of the enemy air defense system, the profile of the ground surface along the path to the target, and taking into account the psychophysiological capabilities of the crew. Specialists think that for this purpose it is necessary to have aboard a special device reproducing the profile of the ground.

Aircraft control commands are produced by means of an on-board computer with a storage unit of large capacity. The storage unit keeps the flight characteristics for the entire aircraft speed range and the dynamic characteristics for various positions of the aircraft in space. Using these data together with the information about the angle of attack, the distance to ground obstacles, their height and the closing speeds, the computer calculates a parabolic flight trajectory (Figure 2). Such trajectories ensure optimal vertical maneuvers that avoid obstacles at minimum altitudes.

Piloting at low altitudes is very difficult due to the limited field of vision and the time of observation of a given target region. This imposes increased requirements on the accuracy and range of the navigational system

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(2) The Mach number is equal to the ratio of the speed of flight to the speed of sound at the same altitude.

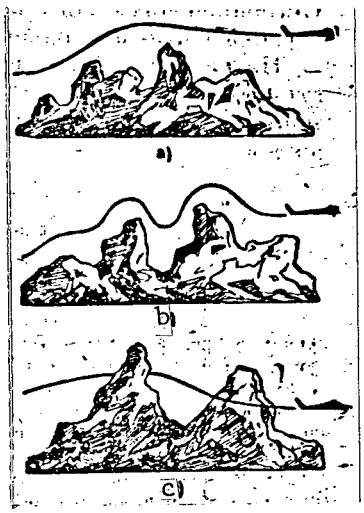

Figure 2. Methods of flight around ground obstacles.

a - a flight around obstacles at a minimum safe altitude; b - a flight following the relief of a locale; c - a flight around ground obstacles using a course maneuver.

that must ensure that the target falls into the field of vision of the on-board radar and that the plane stay in the target area long enough so that the pilot or the navigator can recognize it.

What are the basic characteristic features of the pilot's activity during a low-altitude flight? First of all, the required accuracy of trajectory control becomes greater, particularly in the longitudinal plane. Secondly, /9 the flow of visual information is shortened. Thirdly, the cost of a piloting error sharply increases. As a result there occurs a change first of all in the significance of messages (information) from the piloting and navigational instruments. The altitude control increases noticeably (it involves an active monitoring of the readings of several instruments and their comparison). Of course, if the flight was done on instruments only, all this could be interpreted as partial changes. However, at low altitudes the pilot also solves crucial tactical problems: he is actively searching for small-sized targets, and upon finding them, carries out an attack which involves complicated maneuvers. All this requires a high degree of training in the distribution of attention between the instrument panel and the ground orientation points. By turning his attention away from the ground even for a short time (1-3 sec), the pilot may miss the required orientation points.

Thus, the difficulties involved in visual orientation are deepened by the necessity of a constant doubling of attention between the visual search for the target and the control of flight by means of instruments. The complexity of visual orientation is caused by the greater speed of flight and the turbulence of air resulting in a continuously bumpy ride.

In a flight at low altitudes the pilot's psychological tension is higher due to the closeness of the ground. In addition, the altitude control instrument (barometric altimeter) makes specific errors, and, which is most important, its very principle of operation does not take into account the variations of the local relief, which forces the pilot to compare its readings with the readings of the radio altimeter, usually located far from the main group of piloting instruments. This results in the frequent turning of the head to monitor the natural and instrument information. And this in turn facilitates the occurrence of Coriolis accelerations(3), which significantly change the muscle tonus. Often by turning his head the pilot may involuntarily displace the control lever from neutral, which at a low altitude is dangerous since the ground is very close to the plane, and the effectiveness of /10
control surfaces in the dense atmospheric layers is much greater than at high and medium altitudes.

These features of a flight at low altitudes increase the nervous and emotional tension, and no doubt affect the quality with which the flight tasks are carried out. It will be correct to say that this type of activity is very difficult even for a well-trained pilot. In this connection there are proposals to automate the piloting process at low altitudes. It is assumed that in this case the automatic control will enhance the efficiency of performance and improve the conditions of the pilot's work. Reliable automatic control will not only eliminate the feeling of the dangerous closeness of the

(3) Coriolis (or rotational) acceleration is due to the fact that when the head is turned the otoliths in the ear participate in two types of motion: rotational (of the head) and translational (together with the aircraft).

ground that constantly hangs over the pilot but will also reduce his "division" of attention.

Abroad there are views that it would be desirable to construct for the existing planes a device making up for the deficiency in the altitude information obtained by the pilot, for example, a device like a "talking altimeter." In particular, the last straight line of the flight toward the target should according to some proposals be accompanied by a steady sound that would rapidly stop as soon as the vertical rate of descent exceeds 10m/sec. A short-lasting sound will not tire the pilot. On the contrary, it will become a psychological stimulus to the nervous relaxation since the pilot will become convinced that there is an active protection aboard the plane ("phenomenon of protection"). In addition, sound indication will eliminate frequent turns of the head.

In the view of foreign specialists another promising technical device is in the form of projective indicators. In this case the fundamental instrument information is projected onto the front glass of the cockpit. When displays of this type include command parameters projected onto the front glass of the cockpit, the pilot is able to continuously receive instrument information without turning toward the instrument panel. The image on the glass, focused at infinity, does not interfere with the perception of ground orientation points.

The altitude control may be achieved using peripheral vision, using the so-called paravisual director instruments which will be described in more detail below. Command signals about the loss of attitude will be displayed by means of a movement of black bands across a white background and will be perceived by means of peripheral vision. This type of display provides the pilot with additional visual information about the attitude of the plane, and creates conditions for a distribution of attention.

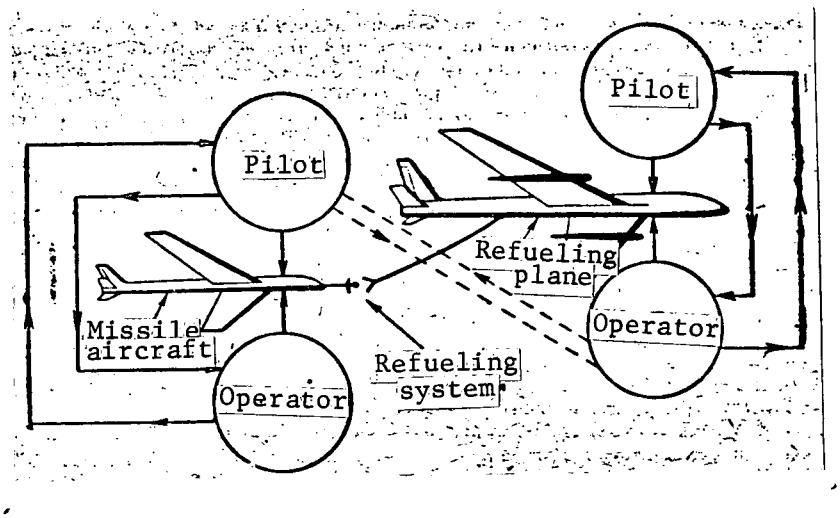

Figure 3. The block diagram of the complicated cybernetic system "man-man-machine-man-man-machine".

In-flight Refueling. As the aircraft technology progresses, the combat tasks carried out by the pilot become more and more complicated. There appeared a completely new type of aircraft, namely the strategic missile aircraft. It flies at distances of many thousands of kilometers from its base. In this connection there arose a new problem: How to refuel them without reducing the combat readiness of the jet-powered giants traversing the expanse of the fifth ocean? And the solution was to refuel in flight! Thus there appeared a new type of the man-machine system: a cybernetic link involving man-missile aircraft-fueling plane-man (Figure 3).

In-flight refueling requires from the crew that they withstand enormous nervous stresses and is accompanied by emotional pressures. The pulse rate of the operators sometimes reaches 180-186 beats per minute; the breathing rate reaches 50-54 cycles. Sometimes a disturbance of the breathing rhythm occurs. The body temperature rises. Sometimes during only a single flight of that type a man loses 5% of his weight. This means 4 kg if the pilot weighs 80 kg! Weight-lifters, removing extra weight in a steam bath, lose only 1.5-2 kg. This is the emotional cost of the flight's stress.

It should be noted at once that these physiological changes are noticeably lessened if the pilot is well-trained and experienced. When training how to refuel in flight in the first two flights without assistance, the pilot's heart /11
beat usually reaches 180/min, and the breathing frequency 50 cycles/min. After a month the heart beat does not exceed 130-140 beats per minute, and the breathing rate decreases by a factor of 2.

The nervous and emotional stress accompanying in-flight refueling depends on a number of causes among which the most important are the complexity of the task and the degree of preparation of the pilot. Psychological stress arises due to the so-called space stress that appears when flying in formation with a refueling plane when the boundless space of the sky becomes "narrow" due to the closeness of the other plane. But the most important reason is this: the requirements on the accuracy of the plane's trajectory control increase to an extent greater than in any other maneuver. If in normal free flight the permissible deviation from a given trajectory is measured in tens of meters in altitude and hundreds in lateral deviation, then during refueling (at the moment of contact) we are dealing with tens of centimeters!

A lot depends on the individual characteristics of a pilot. Even though a strict selection of pilots is a rule, in this case also the personal characteristics must be taken into account.

All this is a domain of engineering psychologists. Using their recommendations, one constructs various devices that facilitate in-flight refueling. Many other complex tasks are also solved by engineering psychologists. This will be discussed later.

HUMAN ANALYZERS

One of the channels of direct coupling between a man and a machine (pilot-aircraft) in control systems is in the form of a coupling like a

indicator-analyzer. This is where the transfer of information from a machine to man takes place. In order for a signal carrying information about the state of a controlled object to be received by the operator, it must first of all have a physical form such that it will be perceived by human senses. A perception can be defined as an awareness by the human mind of the individual properties and qualities of objects directly acting on the sense organs. /12

Perceptions serve as the starting material and a basis for other more complicated cognitive processes in which the human cognition goes beyond the framework of individual properties and qualities of objects and phenomena. For example, the navigator and operator of a radar station see only light points on their radar screen. But thanks to a developed imagination and ability to conceptualize, the navigator is able to see a complex air situation on the basis of those simple perceptions.

Perceptions are characterized by quality, strength, and duration. The quality transmits the peculiarity of the object in question. For example, the red or green color of the landing gear signal lamps conveys the peculiarity of a certain mode of operation of that mechanism. The strength of a sensation transmits the degree to which a given quality is clearly expressed. Thus, the noise of an operating aircraft engine can be heard more strongly or weakly depending on the location of the fuel crane. The duration of a sensation tells us about the length of time during whcih the sensation is retained. For example, flashes of fire give rise to short light sensations, and a signal siren causes a long auditory sensation.

Perceptions came to be divided into visual, auditory, motoric, gustatory, olfactory, tactual, sensations of pain, of temperature, organic, and vibrational.

Perceptions are due to the operation of special nervous and physiological units, called analyzers that have in principle identical construction. Each of them consists of a receptor, transmitting path (nerve), and a central unit in the brain cortex where the transmitting path ends. Man is equipped with a large number of various analyzers. Each of them is adapted to sensing certain properties and qualities of objects, and all of them can be divided into three groups.

The first group includes analyzers whose receptors are located on the external surface of the body and receive everything that occurs outside. These include the organs of vision, hearing, smell, and touch. The second group includes the organs of touch located inside the human body, and its tissues. They enable us to sense definite states of the organism: hunger, fatigue, pain, stress, etc. The ability to correctly appraise the state of one's own organism is very important in the activity of any operator. The third group includes those sense organs that signal the degree of stress in muscles and tendons. They enable us to find our orientation in space and to estimate the position of our body.

When designing and constructing aircraft instruments and indicators the most important question is that of the choice of a physical alphabet of signals, i.e., the choice of the corresponding symbols, "encoding" a given flight parameter, say the altitude of flight. Optical, acoustical, and radar signals can be used for that purpose.

When designing display units and organizing the general conditions of an operator's activity (where any member of the crew may be considered an operator), it is important to keep in mind the variation in the sensitivity of the sense organs in the course of operation. Thus, if in the course of an operator's activity the eye adaptation to darkness (or light) is required (for example, when working in the daytime with an on-board radar screen), then the signal must be given with the proper magnitude and duration. Incidentally,

among the sense organs supplying us with information about the surrounding medium, the eye holds the first place. More than 85% of all information in the course of a control process is obtained visually by the operator. It is not surprising then that so much attention is given to a rational design of the instrument panels, methods of data display, etc.

SCIENTIFIC ORGANIZATION OF WORK IN AN AIRCRAFT COCKPIT

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Academician A. A. Kharkevich wrote: "In our time there arose a new situation in which it is required for man to communicate with a machine while jointly performing very complicated functions. This involves a whole number of problems among which the most important ones involve the creation of both symbols and languages that can be used in the communication between man and a machine...Without recognition, any kind of communication of people among themselves, or man with a machine is impossible." The process of the recognition of a language "spoken" by a machine may in turn affect the behavior of the operator and his efficiency.

Studies show convincingly that the efficiency of the man-machine system greatly depends on the operator's fatigue level and his psychological tension. Psychological tension accompanies situations that very often occur in flight since it is usually associated with the necessity for an accurate, fast, and coordinated functioning under the conditions of interference and time limit. The state of tension appears when there is an emotional and mental overload, created by the difficulty of the problem to be tackled. An extreme form of the psychological tension is the so-called state of stress. The latter involves a disturbance of the human behavior all the way up to a nervous and emotional breakdown. In the state of stress the reliability of a man as a member of a control system declines catastrophically.

According to the U. S. Air Force data, in recent years 60% of breakdowns and accidents occurred exclusively because of subjective factors caused

by the psychological tension of the crew. The problem of the battle against mental stress has assumed great importance as the automated systems controlling the fire, navigation, and guidance, landing on small airstrips become more developed and complicated, and as space flights become more sophisticated.

In what way can the biologization of machines (i.e., figuratively speaking, an "adaptation" of machines to man) lower the mental stress? To answer this question we shall have to recall the chief stages of an operator's work.

A human operator in the process of his work receives useful information, converts it into control information, and gives commands or himself carries out certain control actions. The scheme of the information conversion by the man consists structurally of three stages: 1) reception of information, 2) appraisal and the making of a decision, 3) the carrying out of the decision. The task of aviation engineering psychology is to facilitate as much as possible the work of the pilot in each of these stages. /14

During the first stage the operator is flooded with enormous amounts of information. The problem is that a flight of a modern jet plane is unthinkable without monitoring numerous flight parameters, and as the flight becomes more complicated and systems of higher accuracy are placed on board, the number of such parameters becomes greater and greater. If in the beginning of aviation the pilot was in an open cockpit, and felt movement with his own cheek, while the altimeter, according to the long-time pilot, major general Academician V. S. Kulebakin, was fastened to the knee, then today the cockpit contains such a great number of flight indicators that they sometimes cannot be all put on the instrument panel, and the designers in a number of cases have to place them on the cockpit canopy.

Large amounts of information do not help the pilot but rather strain his attention and distract him from performing the essential tasks. The processing ability of human beings is many times greater than the amount of information

that could be presented to him on screens or tables. In spite of that fact the operator is often unable to receive and process the incoming information within the required time. The point is that the information itself is presented to the pilot in a rough form, using a "language" that he can understand poorly or with difficulty. For this reason it became extremely important to develop a simple "man-machine" language", i.e., an efficient way of information encoding by means of which the current air (space) situation and many other important situations could be reflected simply and conveniently, as if in a mirror.

One of the ways of solving the problem consists of an optimal distribution of indicators in the visual field of the pilot. It was found that best recognition occurs when human beings view an image within the viewing angle of $\pm 15^{\circ}$. For this reason it is vitally important that the essential instrument such as the artificial horizon, the course system indicator, and other indicators in accordance with their importance be placed in the central portion of the instrument panel. The instruments that are less important from the point of view of results are placed on the sides of the panel, and are received by the peripheral vision at an angle $\pm 25^{\circ}$.

The reading parts of instruments can also be redesigned. Three types of instruments have become most widespread: instruments with a needle moving against a stationary scale, instruments with a scale turning in the back of a stationary pointer, and instruments such as counters. Each of these /15
types of instruments has its merits and drawbacks. At the same time it turned out that, other things being equal, the errors in taking readings of instruments having a vertical or linear scale are 35%, semicircular - 16%, "window"-type scale or the so-called band instruments (moving face of an instrument moves past a stationary needle located in a slit) - only 0.5%.

We know that an operator is usually unable to combine an accurate and fast numerical estimate of a large number of individual indicator readings with a

qualitative appraisal of the situation as a whole. In order to facilitate such an appraisal it was proposed to construct integral (combined) instruments. In the simplest case they are instruments with several needles, each of which represents one of the groups of related parameters. In the British piloting system of a fighter plane, for example, a single scale contains the indicators of the magnetic course, azimuth, course angle of the guiding radio station, omni-distance, and certain tactical parameters. The use of combined instruments results in a reduction of the total number of indicator scales on the panel, their more compact grouping, and a reduction of the recognition time. /16

The combining of the indicators of several instruments also turns out to be very useful for giving the pilot the complex information about the position of the plane in space. This is why the piloting and navigational system also includes a navigational instrument, sometimes called an "indicator of the situation in the horizontal plane" (Figure 4). It consists of the compass indicator (course system), indicator of the course and glide-path radio receivers, omnidistance indicator, and finally of various setters (of the course and azimuth). In certain cases it also includes the radio compass indicators.

Compass indicators usually provide an indication showing "the view from the aircraft toward the ground"[4], since in this case the crew obtains a clearer picture of the aircraft's position in the horizontal plane. The needle of the course radio receiver indicator is used not only during the

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[4]The compass, artificial horizon, and certain navigational instruments belong to the group of the piloting and navigational equipment with the so-called "representative indication." In principle several types of representative indications are possible. Two of them have become very popular; "the view toward the aircraft from the ground" and "the view from the aircraft toward the ground," i.e., an indicator models, as it were, the flight differently depending on the "point of view," depending on whether the observer is on the ground or in the aircraft. Thus far there is no agreement on the absolute usefulness of each method for all indicators. According to the foreign literature, the piloting instruments should simulate "the view toward the aircraft from the ground," and the navigational instruments "the view from the aircraft toward the ground."

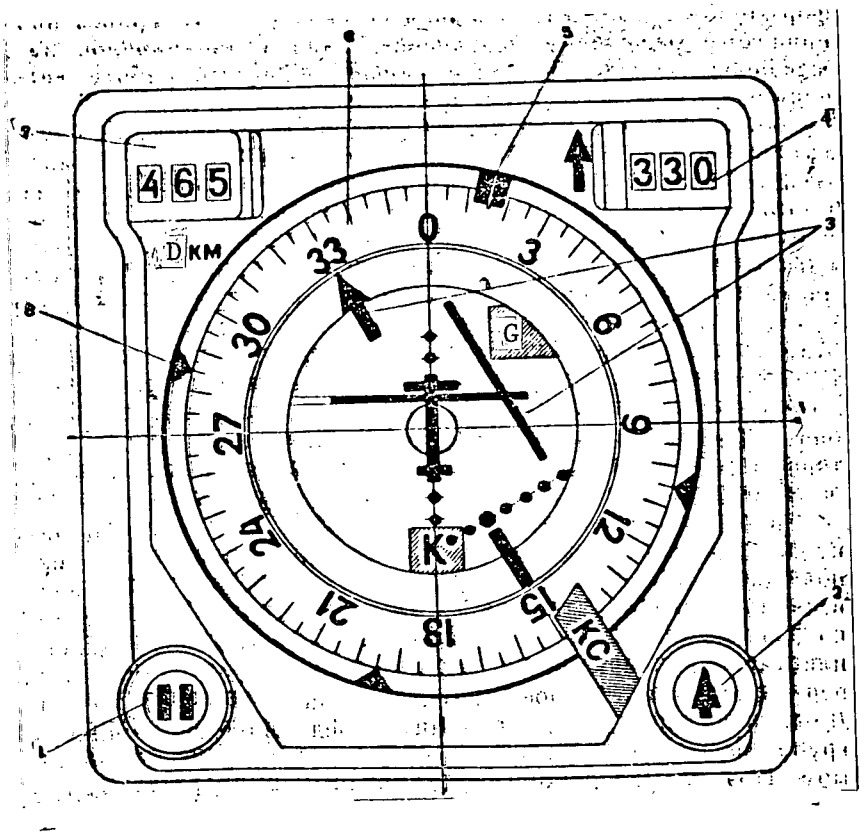

Figure 4. An indicator of the situation in the horizontal plane.

1 - hand of the course setter; 2 - hand of the azimuth setter; 3 - azimuth needle and a strip; 4 - given azimuth; 5 - bearing index; 6 - compass scale; 7 - omnidistance; 8 - command course index.

landing approach, when it shows the location of the radio signal zone of the course radio beacon, but also during a flight with a prescribed route. In the latter case the needle indicates the deviation of the plane from the path specified by the navigational computer or the radio beacon.

The face of the navigational instrument contains handles used to set the indices of the given angle and azimuth. Automatically operating flashes-blinkers are provided for the purpose of signaling any malfunctions of the course system and the course-glide radio beacons and receivers.

Piloting based on command needles along with the positive features (decision is made, the ability to survey the off-board space is enhanced, etc.) forces the pilot to concentrate mainly on the command piloting instrument, which, of course, reduces the amount of attention given to other instruments. The case is different, however, when the so-called paravisual indicators are used. /17

The basic element of a paravisual indicator is a rotating cylinder with a dark spiral line drawn on its surface. The use of these indicators is based on the ability of the human eye to notice moving images not only when they are in front, but also when they are on the side, above, or below the line of sight, taking advantage of the so-called peripheral vision. Due to this fact it is possible to simultaneously follow the readings of all instruments placed on the instrument panel (which is not that easy when piloting on the basis of command indices), and to follow the motion of the paravisual indicators located outside of the panel.

One of the three indicators belonging to a set is in front of the pilot. /18 It serves to issue commands concerning the bank angle. When such a command appears the cylinder with the spiral line begins to rotate in such a way that the movement of this line shows the direction of the necessary bank. When the bank angle reaches a value needed for the plane to change to a given path, the cylinder starts rotating.

Thus there is an analogy between the deflection of the command needles and the rotation of paravisual indicators: the direction of deflection of a command needle and the direction of motion of a spiral line show the directions of the required bank angle. When the necessary bank angle is achieved, the command needle returns to its null position, and the paravisual indicator stops.

Two other indicators, located on the sides in front of the pilot, are used to indicate commands concerning the pitching angle[5]. The direction of motion of the spiral line in these indicators shows whether the pitching angle should be increased or decreased. A similar set is also provided for the co-pilot.

The use of paravisual indicators permits us to solve one other problem: the transition from a flight on instruments to a visual-contact flight under complex weather conditions. As we know, such a transition (just as the reverse transition) requires a certain amount of time from the pilot. After a transition to visual-contact flight, the pilot following the position of the airplane through the cockpit canopy, is unable to follow the readings of instruments located on the instrument panel. In addition, as before he needs information about the speed, altitude, etc. Such information must be given to him by the navigator or another crew member, which involves difficulties. For this reason electronic-optical devices are being constructed and perfected which project the instrument information onto the front cockpit canopy or a special screen located in front of the canopy.

One of the most important advantages of such devices is the fact the image is sharply focused, and thus it appears removed to "infinity." Therefore, the illusion of observing the external space is created, which means that the pilot's eyes do not need to become accommodated to ground orientation points when changing to visual-contact flight.

The amount of the parameters displayed in such devices is quite large. They include first of all the horizon line which is displayed on the gyro-vertical. Due to the "view from the aircraft toward the ground"-type of display, used in a number of indication systems, the line of the artificial

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[5] The pitching angle is the angle between the longitudinal axis of an airplane and the horizontal direction.

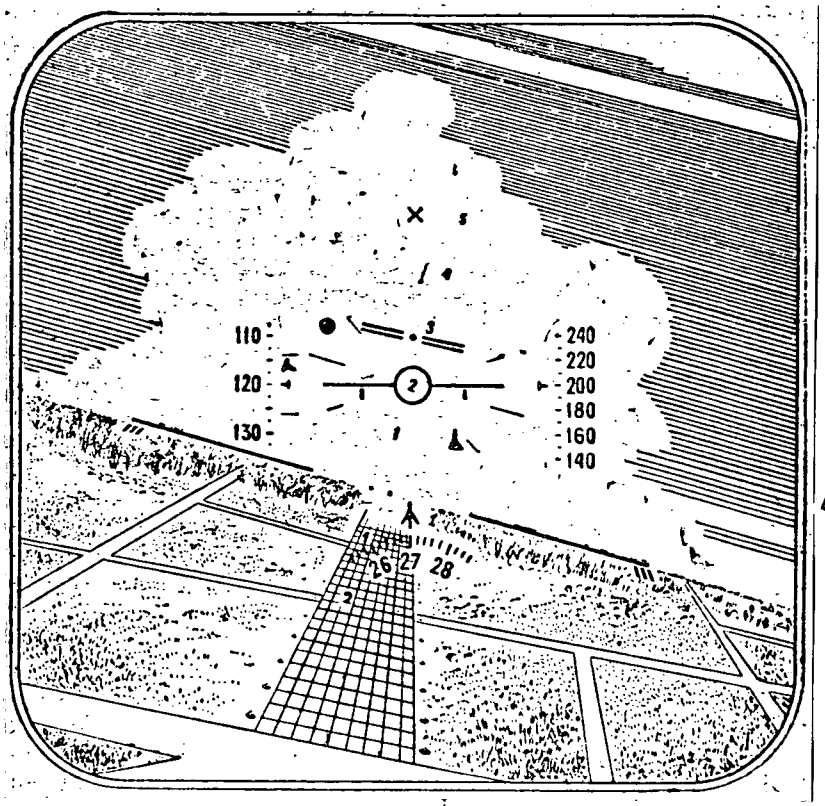

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Figure 5. An indicator in the front cockpit canopy.

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horizon is always parallel to the line of the actual horizon, and the stationary aircraft silhouette lies in the center of the image. During the landing approach using the director instruments one must combine with the silhouette the command index controlled by the signals from the piloting system's computer. The form of the command indices is diverse: most often it is such that a single image is produced when they are combined with the airplane silhouette.

In one of the models of such an indicator (Figure 5) the command index consists of a central point and two pair of parallel lines on each side. In this case the command index indicates the necessity of banking to the left and of increasing the pitching angle. When this is done, the central point will appear inside the circle with the airplane silhouette, and the silhouette

wings will appear between the parallel lines. To make the pitching angle readings more accurate, the indicator has a widely extended scale for that angle.

The left-hand side of the diagram shows the scale and the air-speed indicator, and the right-hand side — the altitude indicator, and below — the course indicator. A sharp triangular index under the silhouette indicates the location of the plane relative to an equal-signal zone of the course radio beacon. An identical index to the left of the silhouette shows the location of the plane relative to the equal-signal zone of the glide-path radio beacon.

All these indices are of different color. Their brightness can be regulated within a wide range. This principle of indication has great advantages over the usual type of indication with the aid of instrument panels, particularly /20 under the conditions of poor visibility.

Another method of the always useful (within the limits of the resolving power) reduction of the eye movements over the instrument panel and of combining the received signals into a whole image is based on a special selection of scales and instrument indicators. The selection may be accomplished in such a way that when given flight conditions are maintained the pointers and indices on all instruments stop in the 3 o'clock position, for example, or along the horizontal and vertical reference lines (Figure 6). In this figure the horizontal reference line is associated with the parameters that change by controlling the plane longitudinally, i.e., by moving the control stick and the gas control forward and backward. These parameters include: the pitching angle, the angle of attack, the air-speed[6], the Mach number, the

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[6] The angle of attack is the angle between the air-speed vector, or to be more precise, between its projection onto the plane of symmetry of an airplane, and the longitudinal axis of the airplane. The air speed is the speed of flight of the airplane relative to the air.

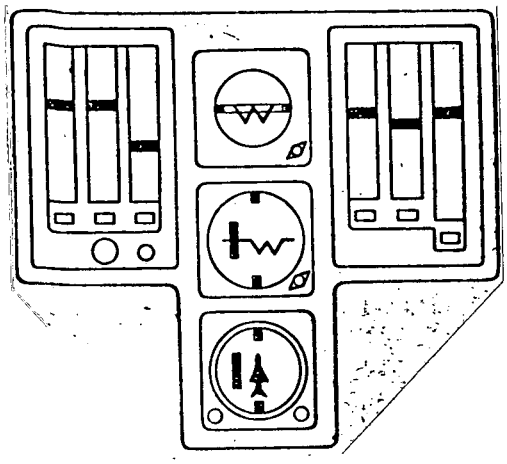

Figure 6. The instrument panel of the piloting and navigational system in a modern fighter plane.

climb rate, altitude, and acceleration. The vertical reference line is associated with the parameters of the lateral motion: the bank angle, the angular rate of yaw, and certain data on the navigational and tactical situations.

An even greater increase in the efficiency of reception is achieved by using integral indicators that give a picture-type representation of the situation. Such indicators are called in the foreign literature the contact analogs, or conalogs. Conalogs essentially simulate the conditions of visual contact, and might be said to create the effect of direct contact.

A conalog developed for the American atomic submarines converts the readings of 8 indicators into a special representation of the motion and location of a submarine on the screen of a cathode-ray tube. A given direction of travel is represented in the form of a path going toward the horizon. The path is in the form of a light strip subdivided by lateral dark lines that seem to go in the direction of the rudder as the submarine moves. The operator has the feeling as if he were looking through the front glass under water, and just as the automobile driver, he tries to maintain the submarine within the "roadway."

Conalogs may be of the optical-electromechanical or television type (Figure 7). In certain models of aircraft conalogs of the first type the necessary pilotage information in the form of light indices is projected directly onto the front portion of the cockpit canopy. In this case the pilot

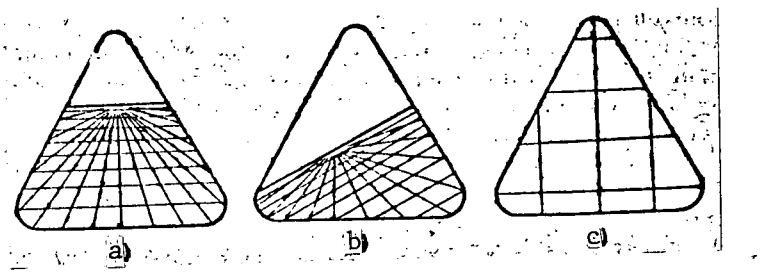

Figure 7. Image on conalog screen. a — horizontal flight; b — bank; c — vertical dive.

is not prevented from observing the front hemisphere for even one second, which is particularly important during the landing approach. In another conalog the entire instrument panel "degenerates" into two flat television screens. One of the screens, located vertically in front of the pilot, is covered with a transparent luminophore film. On a clear day the pilot can see the terrain ahead of the air plane through the film, just as well as through the plexiglass of an ordinary canopy. Under poor visibility conditions such a "window" becomes a flat television screen on which one can see the image of the same terrain but with the help of the on-board radio instruments. /21

Simultaneously the same screen gives the information on the speed, altitude, course angle, and other flight parameters. Another television screen about 20 cm. in diameter is located horizontally in front of the pilot. That screen shows a moving image of the terrain, corresponding to the altitude of the flight. A point in the center of the screen shows the current position of the airplane. Concentric circles on the screen are used to indicate the azimuth, the distance to the return or final point of the route, the fuel level, the maximum distance that can be flown by the airplane on the remaining fuel, considering the wind, and other factors.

The second stage of the information conversion by the pilot consists of its appraisal followed by coming to a certain decision. In this stage the information is analyzed and generalized, the relative priority of the necessary operations (a turn toward the given direction of travel, an increase in altitude, descent, etc.) are set. The psychological content of the second stage involves the functions of the higher nervous system, an act of thinking.

Thus far we know relatively little about the dynamics of the operation of the brain. But even today engineering psychology can indicate ways of designing the so-called director (command) instruments that free the pilot from simple but tiring logical and addition operations. These operations frequently require individual training to become habits. A director pilotage /22
instrument, which is being developed by one of the foreign firms, might be said to represent a combined instrument with a single pointer. The pointer indicates what the pilot must do at a given moment, for example: "close the throttle" or "elevator up," i.e., it may be said to "give commands" (this explains the name of the instrument): "move the throttle control!" or "move the steering wheel toward yourself!". Director instruments have become most popular in landing systems.

The principle of operation of one such promising director instrument is based on an automatic analysis of the readings of several piloting instruments (gyro horizon, altimeter, rate-of-climb indicator, glide-path beacon comparator). The analysis is done according to a preset program by the on-board computer. A deviation of a director instrument needle is proportional to the algebraic sum (with their significance coefficients) of the magnitudes of the pitching, altitude, vertical speed, and the deviation from the glide-path signals. The pilot by moving the altitude control tries to hold the needle at zero. In this process the actual pitching angle is compared with its required value, which is found by the computer from the value of the vertical speed of the airplane and the deviation from the equal-signal zone of the glide-path radio beacon.

The last, third stage, of the operator's work is the stage in which actions are performed. In manual or semiautomatic piloting the pilot himself moves the throttle control, the control stick, presses the pedals, turns on or off the equipment, i.e., reacts motorically. The movements themselves are simple. However, the entire complexity of the actions performed depends on their regulation by the central nervous system. The efficiency of even the simplest elementary movements is determined by a whole series of various factors, the state of the nervous and muscular activity, motor habits, etc.

The actions of the operator, whether he is a pilot, navigator, cosmonaut, or flight director, should occupy, just as all the preceding operations, a minimum amount of time. Therefore it is clear that the control organs (the control handle of the orientation system, the throttle control, etc.) must be adapted to humans, i.e., must agree with the motor characteristics of human beings.

Usually the designers try to place the control buttons and switches on an inclined panel in front of the instrument panel so that one could clearly see the correspondence between the location of the control and measuring instruments, tumblers, and keys, affecting the parameters being measured. The force necessary to move a remote control organ is usually insignificant. However, if one takes into account how many times such actions are repeated during a flight, then one can see that also here the physiological peculiarities of man cannot be discounted, for example, it will be remembered that man develops the greatest force in the direction toward his body, and it is easier to produce that force while sitting, rather than standing. The force increases if the entire hand and the arm participate in the action. On the other hand, if just one finger participates in the action, much lower amounts of energy are expended. /23

The accuracy of control over the applied force is identical for hands and legs. The hand usually moves faster in the horizontal rather than the vertical.

It is more convenient for the right hand to turn counterclockwise, and for the left hand — clockwise. A continuous curvilinear movement can be carried out faster than a movement involving sharp changes of direction. A movement with an unrestrained sweep can be performed by humans faster and with a smaller expenditure of energy, than a restrained movement. A pressing movement can usually be carried out more accurately than a displacement, but when it is necessary to combine a pressing movement with a displacement, then the latter is more precise.

In the design of the control panel it is taken into account that people associate the direction of motion of a control organ with a correction of the deviation of the instrument pointer and the direction of the response reaction of the controlled object. This is why a clockwise movement forward and up is associated with an increase of a parameter. Buttons, handles, and other organs of control are placed in an area 0.7 m in radius. However, the optimal height of the panel is approximately 0.8 m.

Human motor reactions are known much better than the perception processes, let alone the thought processes. Indeed, today's studies of the motor reactions are distinguished by their greater accuracy, a description of the processes in the language of transfer functions, and frequency characteristics. This type of description of the human operator is extremely important in, for example, the study of the dynamics of a fighter-interceptor aircraft guidance, the optimization of the control over the future maneuverable spacecraft, their soft landing, docking, etc.

What is the transfer function of man? In automatic control theory the transfer function is defined as a mathematical expression characterizing the ratio of the output parameter of a system to the input signal. In principle, any complicated system, including a human operator, can be decomposed into individual dynamic links. Each link has its own transfer function. In the

construction of models of an operator three types of links: amplifying, inertial, and driving ones are used. /24

In the amplifying link, the output parameter changes immediately after the appearance of the input signal. However, in an inertial link the output parameter assumes a steady value, not at once, but after a certain time. Thus, this link possesses a certain inertia which is characterized by the time constant τ. The inertia of a link is proportional to τ. The driving link has an interesting property. Here the output parameter is proportional not to the magnitude of the input signal, but to its rate of change, i.e., the driving link might be said to predict that the magnitude of the signal will be in the near future, after a certain time T_ϕ. The greater T_ϕ, the further into the future can the prediction be made, and the greater the effect of prediction.

In addition to these three linear dynamic links, i.e., links in which there is a linear (proportional) relationship between the output parameter and the input signal, there also exist nonlinear dynamic links. The most typical nonlinearities are of the form of "the insensitivity zone" and "saturation." These nonlinearities characterize that region in which input signals vary, that does not cause any change in the output parameter of a system. Thus, in the case of nonlinear links the proportional relationship between the input and output does not hold, which is often (but not always) undesirable from the point of view of the stability of the dynamic system.

In addition to the transfer function, the frequency characteristics give an equally clear idea of the dynamic properties of a system. The amplitude-frequency characteristic is very convenient in practice. We know from the theory of oscillations that any periodic input signal can be represented as a sum of oscillations of various frequencies. It turns out that each system reacts peculiarly to signals of various frequencies: certain frequencies are passed well; others, however, are passed poorly or are completely damped out. The amplitude-frequency characteristic represents the relationship between the

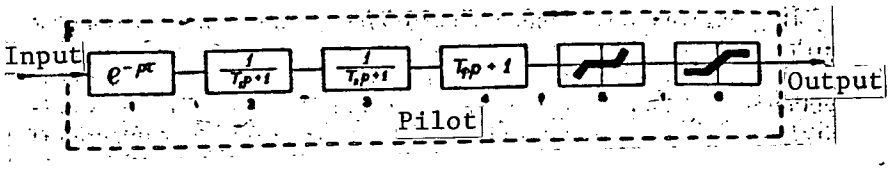

Figure 8. A dynamic model of a pilot.

p is the so-called Laplace transform operator that establishes a relationship between the frequency and time characteristics of a signal; τ, T_1, T_2, $T\phi$ are time constants of the dynamic links.

output amplitude of the oscillations and the frequency of the input signal.

Man as a dynamic system has his pass band, i.e., the frequency region beyond which he no longer reacts to an input signal. It is usually assumed that the human pass band lies in the region from 0 to 2.5 - 3 Hz. Thus, man passes the low-frequency signals well. However, if the frequency of the input signal is increased and goes above 2.5 - 3 Hz, then he simply cannot react to it.

Experiments have helped us to construct a dynamic model of a human operator (Figure 8). According to specialists, this model reproduces the behavior of an operator in the region of low-frequency signals with an accuracy of 85-90%. As we can see from the diagram, man as an element of a control /25
loop can be schematically represented as a series combination of four linear and two nonlinear links(7).

(7)Here and below, we are talking not about the reproduction of the behavior of an operator in general, but only about certain fairly sharply defined particular so-called "machine-like" functions of the operator, performed, let us say, when stabilizing an airplane on a given course. Apparently up to this very day, we can appreciate the truth of the words of Academician A. N. Kolmogorov who said that today we are still very far from the description of higher forms of human activity. We have not learned thus far to give objective definitions of the many categories and concepts occurring here, let alone simulate complicated forms of such activities.

The first link characterizes the process of taking the instrument readings. It is accompanied by a delay of time constant τ. The second (inertial) link describes the process of decision making. The third (inertial) link describes the process of the nervous and muscular action on the control handle. The fourth (driving) link shows that man can control not only a deviation, but also the rate of change of the deviation, as if anticipating the course of events. The fifth and sixth links characterize the nonlinearities peculiar to man: the operator does not react to very weak signals, and in the case of a sufficient error signal he tends to maintain the rate of liquidation of that error at the same constant level.

The data on the mental stress of the crew during flight and the errors arising for that reason must be taken into account, both in the stage when a sytstem is tested and during the preparation for flights. They must also be considered in an even earlier stage: when designing the systems. This refers not only to the example of mental stress, but also to a majority of the engineering psychology recommendations concerning human factors.

It is impossible to disagree with the well-known test pilot M. L. Gallay, who in his discussion of the so-called "strict" aircraft, wrote: "No! An airplane must not demand from its human operator the same amount of attention and physical preparedness as, for example, the work of a circus acrobat or a juggler. The reason for it is not only the relative mass character of the flying profession as compared with the circus acrobats, but primarily because to the pilot the piloting of an airplane is not a goal in itself. A greater part of his attention should be freed, so that he can competently carry out other functions, for the sake of which the flight was undertaken in the first place. Those test pilots that proved the piloting capacity of the airplanes that have fallen into their hands, only because of their mastery, have unwittingly done a disservice to our aviation. In addition, they did that under sports and recreational conditions of flight. However, when an airplane similarly tested is piloted not by a test pilot but by a fresh piloting school /26

graduate, not in order to train and perform aerobatics but to carry out combat duties, the positive features of the plane often turned out to be its drawbacks...".

This, of course, does not mean that the operation of the new instrument will not require any effort from a trainee. M. Gallay says specifically that it is necessary to fully adapt oneself to the cockpit, and that only when the plane is left face to face with the pilot will it reveal (although sometimes not at once) its mysteries. As in the case of people, the mysteries of an airplane may be pleasant and unpleasant. In aviation, those mysteries are supposed to be discovered by the test pilots who must search for the Achilles' heel of each new airplane. The apparatus that the operators of airplane automated systems must deal with is becoming so complicated, and its operation so full of responsibility, that, it seems, the time is ripe to think of creating an institute of test operators, in analogy with an institute for test pilots. The task of test operators will be to discover jointly with the engineering psychologists in the mockup and apparatus testing stage the Achilles' heel of the latter and to prevent the unpleasant surprises to which the crew might be treated in the air.

TECHNICAL LANDSCAPE OF A COCKPIT

Not only the instrument panel, control handles, tumblers, but also the entire cabin of aircraft containing the crew, passengers, and researchers, /27 should as fully as possible be designed considering the human factors. Here we are talking primarily from the anthropometric and physiological point of view. Anthropometric adaptation is characterized by correctly selected parameters of cockpit design, starting with the anatomic features of the human body — its size, weight, physical strength, possibilities of movement taking into account the working position and the characteristic features of the use of the diverse cabin apparatus during flight. Physiological adaptation is defined in terms of the characteristic features of the functioning

of sense organs (vision, hearing, smells, and touch) and the selected parameters of the cabin microclimate (temperature, humidity, pressure, composition of the cabin atmosphere, velocity of the atmosphere — artificial drafts, etc.).

Finally, we are talking about esthetic adaptation, i.e., the emotional satisfaction of people obtained in perceiving cabin parts, mainly, in visual and auditory perception. This type of adaptation is usually achieved by making use of harmonious and proportional parts, of plasticity, color, functionality, i.e., an ease of control or operation, originality, and insight in designing technical elements.

If the anthropometric and physiological adaptation of an airplane cabin to human factors can be accomplished by ordinary airplane and spacecraft designers with the advice from the specialists in the area of aviation and space medicine, then the esthetic adaptation will require that the interior designers, as they are called abroad, be also included among the cabin constructors. Moving ahead of ourselves, we shall show that the methods available to interior designers make it possible to create in the cabin comfort, convenience, and an esthetically pleasing appearance, which are important psychological factors.

The following figures are interesting because they give us an idea of the effect of proper interior design. We know that good sunlight increases the efficiency of work by 10% on the average (directly at the work post by even 20%), a reduction of noise to satisfy hygienic standards increases the efficiency by 40-50%, and a well thought-out introduction of music adds another 12-14% by increasing concentration and reducing fatigue; a rational positioning of control organs may double the efficiency (i.e., increase it by 100%). The effectiveness of rational coloring is also well known to everybody: according to the data published in East Germany, proper coloring may increase the efficiency of work by 25%.

Now it may be said that one of the important creators of beauty in the cabin is the interior designer who essentially carries a certain type of "supply" of engineering beauty in aviation and astronautics. Bridging the gap between /28
beauty and usefulness, the interior designer introduces a useful element of beauty into the very prosaic, utilitarian processes of work and life. This element of beauty helps the entire flight and creates one whole out of the "man-machine-environment" process.

Due to various forms of work-related activity and social relations, man forms a kind of musical ear and the eye sensitive to the beauty of the form, i.e., a sensory perception is transformed into an elementary esthetic perception. When this happens man consciously begins to use the laws of beauty to create such objects that cause an esthetic pleasure. It was noticed a long time ago that certain properties of objects and phenomena of the external world, such as the color, form, rhythm, symmetric location of parts of a whole, their proportionality, harmoniousness, affect man considerably.

The cabin of an airplane, and particularly of a spacecraft, together with the crew, passengers, and researchers should be a part of our earthly life, our nature. We know that nature makes everything beautiful by using such elements of beauty as color, light, form, symmetry, proportion, rhythm, harmony, unity of the whole and its parts. It is of course true that the natural object-and-space environment: architecture, technology, everyday objects, etc., that on the earth are the everyday companions of man, forming his mentality, under flight conditions are impossible to realize.

Thus in an airplane cabin thanks to a cooperation among designers, specialists in the area of aviation and space medicine, and interior designers a special "technical landscape" is created. Its basic objective under the conditions of a long flight when it is possible for attention to become more narrow, and for the speeds of orientation and motor reactions to become lower, is to stimulate the interest in the work-related activity and to reduce by a

conscious effort the undesirable phenomena that accompany the flight fatigue.

A beautification of the object-and-space cabin environment provides a powerful source of sensory information. The esthetic information carried by a "machine environment," produces in man a definite mood, increases or decreases his work readiness. Under the conditions of a long stay in the closed space of a cabin, this type of effect is quite noticeable.

A creation of such a tehcnical landscape, representing a single ensemble of the objects in the machine environment in the crew and passenger cabins: instrument panels, panels and levers used to control all kinds of equipment, is one of the principal tasks of interior designers. Before the designers /29 tried first of all to satisfy the requirements as to the distribution of the necessary equipment whose list is determined by preset tactical and technical requirements, and it was only after this had been done that they tried to somehow adapt the equipment to man. They justified it by saying that the pilot's work requires the ability to adapt to the rigid conditions of a cockpit. Today, however, the designers of cabins and living quarters are expected not only to be strictly rational in their design, but also to create elegance, interesting form, that would correspond to the functional use of a particular piece of equipment.

The interior designer must find a formula in which the functionality of each element of the technical landscape will merge harmoniously into an esthetically pleasing cabin interior. This is not easy, since thus far a designer's intuition not always lends itself to a strict mathematical analysis. The problems faced by an interior designer in airplane construction are very complicated, since the attempt to find within some limits the "region" where man is stimulated by the "rational in the beautiful," is in itself a problem.

During flight it is not only, shall we say, the pragmatic (8) effect of the cabin interior on man that is important. Here it must be clear to us that an airplane cabin must suit more its inhabitant than the designer, since the work of a pilot is an activity that requires not only a high emotional preparation, internalized habits, but it is also a work of creation. The configuration of the forms of objects filling a cabin must be designed in such a way that it will not be disharmonious with the interior. In addition, one must avoid in the cabin the abundance of single-sized and even more, single-form objects that have a tiring effect on man's psyche.

In addition, a designer must always remember to harmoniously combine the functional and esthetic requirements. If these requirements conflict with each other, it may cause not only a simple fatigue but a fully real danger to the safety of flight. It should be sufficient to remember the example given in the introduction. In this example the pilot K. was a victim of the beautiful, enticingly designed, but completely identical switches. The result was an accidental drop of the suspended gasoline tanks that almost caused a flight accident. This means that even an elegant panel with a multitude of eye-pleasing, glittering, but completely identical twin tumblers, each of which has its own, often very responsible, functions, may become a source of very serious incidents during flight. Therefore, the functional requirements must always be given priority before esthetic requirements. /30

Color also has a psychological effect on the human organisms. With its help one can create a certain "emotional climate," thus affecting the emotional attitude toward work. One can neutralize the feeling of heat or cold, one can "remove" tension or feeling of monotony, etc. In this connection there arises a whole series of questions pertaining to the form of the work areas and cabin interiors in both aircraft and spacecraft.

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(8) In this case we mean the effect of a simple adaptation of the working post and the controls to the anthropometric characteristics of a crew member.

Knowing what kind of influence this or other color may exert, the designer can use warm tones for excitement, and cold tones to create a peaceful situation. In the same way a harmonious combination of colors (all shades) may be conducive to more efficient work, whereas a dissonance of the color scheme (mixing of warm and cold tones) leads to fatigue. Psychology of color must naturally be included in the design of aircraft and spacecraft cabins.

A sharp distinction between the field and the ceiling of the cabin, a separation of the working zone of the panels, concentration of attention in the most important portions of the control panel, effectiveness of indication and signalization, these are all tasks that can be most simply performed by means of color.

Interior design boils down to assuring the required comfort as the necessary condition for the optimal work capacity. In this sense the color comfort is determined by the corresponding level of the lighting of the interior as a whole and its individual parts, and a selection of contrasting color relations within limits providing optimal perception. It should be noted that color is most noticeable on matt glare-free surfaces.

Both color and lighting can be used to achieve the effect of the "color shock," which is a type of psychological shock relieving the monotony of a situation and reducing the psychological fatigue. A general coloration of interior, its color composition, are usually also selected on the basis of purely esthetic considerations, and for this reason they are significant sources of sensory information.

In addition, the interior designer must consider the ability of color to "come closer" or to "move away" when used against a certain background. This permits one to correct somewhat certain defects of form by forcing man to perceive the cabin differently. Thus, dark colors against a light background always seem to move away, just as cold colors against a warm background. /31

Light colors against dark, however, just as warm colors against cold, seem to "approach" one and move forward. Colors in a cabin may also perform warning functions. The red color "speaks" of danger, yellow "requires" a heightened degree of attention, and green "denotes" safety or normal conditions.

Now several words about the luxurious cabins of passenger planes. The interior designer "receives" from the engineering designer a specific closed volume that reminds one in its form of a tube that he must modify in such a way that the passengers during flight will feel as comfortable as possible. His task is not to strengthen the construction, but rather to weaken that effect of the tube.

In dealing with problems related to the interior design of the passenger airplane cabins, the interior designers encounter a new phenomenon, namely, that of fashion. The problem of fashion in engineering deserves a separate study, and thus we shall not analyze it here. Suffice it to say that airliner cabins now carry light chairs, covered with blue, red, green fabrics and plastic. They have more light and seem more spacious.

Interior design began to acquire business significance. No matter how comfortable a plane is, air travel is still an unpleasant state to the human psyche. Interior designers are striving to lessen the passengers' fatigue as much as possible. Here, just as in the cockpit, everything plays some role: color, harmony, lighting, noise level, texture of wall paneling. For example, in designing the airplane "Caravelle" the French designer R. Mellit as an experiment used glass of different colors in the windows. The experiments showed the color of a tea rose was the most pleasant to passengers.

In closing this discussion of cabin esthetics, let us emphasize the following fact. Engineering esthetics brings to the crew eye-pleasing colors and forms, ear-pleasing sounds, economical movements of hands and muscles, ex-

quisite bouquets of smells, and finally, interesting professional work. However, the true beauty and convenience are to us always associated with minimum expenditures of materials and labor both in the manufacture of an object and in its use.

Beauty in aircraft cabins must absolutely be accompanied by economy in their construction.

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Great opportunities also open to engineering psychology in the exploration of outer space. An absence aboard spacecraft of the usual stimuli, sounds, gravitational and magnetic fields, change of day and night, and other "terrestrial" factors, under whose influence the human evolution has taken place and the biological rhythms have originated, poses new problems to the engineering psychologists.

If in aviation an engineering psychologist tries to reduce the vibration level, and the engine noise level in the cockpit, then during a long space flight under the conditions of absolute silence it will be necessary to eliminate the mental stress and create conditions that the crew will find conducive to work. This can be done by reproducing artificially the terrestrial sounds, playing tape recordings, showing movies, etc. Some attention must also be given to solving problems of the psychological compatibility of the space crew members, their organization, and the optimal combination of the "human factors" of each cosmonaut.

The bionic aspects of the man-spacecraft system are interesting. At the present time an exchange of information between a machine and man occurs through a small number of channels. For example, as already noted, the control information proceeds from man to a machine basically in the form of any motor act. Today work is already being done on the communication with machines by

means of voice commands and biopotentials (biocontrol), as well as on the activation of other human sense organs in addition to vision and hearing: touch, smell, taste, and skin sensitivity. An increase in the number of channels over which man can communicate with a machine makes it possible to not only relieve the human analyzers and increase their resistance to errors, but will also permit a surer control of spacecraft under the conditions of heavy overloads (for example, during lift-off from a celestial body to return to the earth).

Already today we can say with certainty that the construction of a whole complex of complicated spacecraft equipment, selection and training of cosmonauts, and operators of the ground tracking and control stations, all this would have been impossible without the achievements of engineering psychology. However, the tasks facing it are even greater, especially in the area of the applied simulation of the processes of the higher nervous activity of man, finding himself under the unusual conditions of spaceflight.

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